

PHOTOVOLTAICS FOR RURAL ELECTRIFICATION IN THE PEOPLE'S REPUBLIC OF CHINA

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ABSTRACT

Rapid growth in economic development, coupled with the absence of an electric grid in large areas of the rural countryside, has created a need for new energy sources both in urban centers and rural areas in China. The most critical need for rural electrification exists in northern and western China, where 80 million people had no access to grid electricity at the end of 1995. In February 1995, the U.S. Department of Energy (DOE) signed an Energy Efficiency and Renewable Energy Protocol Agreement with the Chinese State Science and Technology Commission in Beijing. Under this agreement, NREL is providing assistance to several central government and provincial government agencies in China to develop photovoltaic and photovoltaic hybrid applications for rural electrification.

INTRODUCTION

The People's Republic of China is a rapidly developing and industrializing country with a population of approximately 1.2 billion people. Approximately 80% of this population lives in rural regions. The use of solar, wind, and biomass resources for general energy needs is already widespread in rural China. The potential market for the additional use of renewable energy resources for rural electrification applications is very large. For example, in the five northern and western provinces and autonomous regions of Qinghai, Tibet, Inner Mongolia, Xinjiang, and Gansu, there are a minimum of 2.2 million unelectrified households that are located in a region of China where grid power does not exist [1]. For several hundred islands along the coast of China, the development of grid power in the near term is also not feasible.

In the heavily populated regions of China where grid power does exist, there are still at least 20 million households without electricity due to severe shortages of conventional electrical generating capacity based on coal-fired steam turbines and hydropower. In addition to capacity constraints, there are severe reliability problems, manifested in the form of blackouts, poor power quality, and high transmission and distribution losses. There are also concerns related to the environmental impacts of coal combustion in all sectors of China's energy markets. In regions that have access to grid electricity, solar and other renewables can be used to increase electrical generating capacity in both grid-connected and off-grid applications.

At the end of 1995, the total installed photovoltaic (PV) generating capacity in China was relatively small at about 6.6 MWp, of which 65% was used in the rapidly growing telecommunications market, 16% for household electrification, 11% for agricultural and industrial applications, and 8% for consumer applications [2]. Currently, the market for telecommunications systems still represents the largest market for PV systems in China, but the fastest growing market is for remote solar home systems for basic lighting and power for television/radio. PV and small wind technologies are increasingly being recognized as a cost-effective alternative to coal-based power generation and to conventional line extension for meeting rural energy needs.

SOLAR HOME SYSTEM DEVELOPMENT IN WESTERN CHINA

Initial U.S./China cooperation for rural electrification activities in China is focused on the development of solar home system applications for western China. The cooperation has started in the Province of Gansu and will gradually be expanded by the Chinese Ministry of Agriculture (MOA) into additional provinces in western China. The Gansu project is being implemented by the Solar Electric Light Fund (SELF) in Washington, D.C. and the Gansu Solar Electric Light Fund (GSELF) in Lanzhou, Gansu, and builds upon work previously conducted by these organizations. The objective of the present phase of this project is to provide electricity to more than 600 remote homes and schools during the course of the project and help construct an infrastructure for technology deployment in the form of a distribution network for sales and service, a comprehensive training program, and experiments for financing systems through cash and credit sales.

A typical solar home system in Gansu and for most of western China consists of a 20-Wp crystalline silicon PV panel, a charge controller, a 38-AH sealed lead-acid battery, two 8-W compact fluorescent lamps, and necessary wiring. The average retail price of such a system in Gansu is about 2,400 RMB (\$290 US). The lack of credit

experience in rural China necessitates the continued experimentation with installment credit terms to develop a functional credit system. The Gansu project is directed toward poor communities in rural Gansu, using limited subsidies that will be phased out during the course of the project. The planned overall recovery rate for the project is 80%, based on the 2,400 RMB sales price. The province of Gansu has among the lowest annual income levels in all of China for remote farming communities. A revolving-fund account has been set up at the Lanzhou Branch of the China Construction Bank by SELF and GSELF to leverage the project by using customer receipts to purchase more systems.

The Gansu rural electrification project is a cost-shared project with DOE providing 50% of the cost (\$220K USD) and the rest is provided by Chinese partners, including: i) the Gansu Office of the Chinese State Council Office for Poverty Alleviation and Rural Development (\$110K USD), ii) the Gansu Planning Commission (\$44K USD), iii) the Gansu Economic and Trade Commission (\$44K USD), and iv) the Gansu Solar Electric Light Fund (\$22K USD). The State Council Office for Poverty Alleviation and Rural Development in Beijing is a key funding partner working closely with MOA. This Office has a primary responsibility for rural development projects in China and spends over \$1 billion (USD) per year on rural infrastructure projects. The Gansu project is providing a mechanism for introducing the support of renewable energy technologies into the strategic planning activities of the Office.

Three local PV system integrators in Lanzhou are responsible for system assembly and installation, for providing product warranties, and for after-sales support and training. The three companies represent three common types of business organizations in China. The Gansu PV Company is a privately owned company started by a local entrepreneur in Lanzhou. The Gansu Zi Neng Automation Engineering Company is a for-profit subsidiary of the Gansu Natural Energy Resources Institute (GNERI) in Lanzhou, which is a state-supported research institute. The Zhong Xing Electronic Instrument Company is a state-owned manufacturing company of electrical equipment, which has converted from being a military hardware supplier to providing consumer and industrial products and services. All three types of companies form an important distributor and supplier base for developing the rural electrification market in China. These companies are supplying charge controllers, compact fluorescent lights, wiring, and support structures for the project. Some U.S. charge controllers will also be used in the project.

The U.S. will supply components including polycrystalline silicon modules from Solarex, complete USSC Unikit solar home lighting systems that incorporate a-Si:H modules, and batteries from SEC Industrial Battery Corporation that are produced in a joint venture manufacturing plant in Shenzhen. In Phase I of the project, 180 Solarex VLX-20 PV modules, 180 38-AH sealed lead-acid batteries, 10 complete 53-Wp solar lighting kits (consisting of Solarex VLX-53 PV modules, Ananda Power charge controllers, and 65-AH batteries), and 20 USSC Unikit solar home lighting systems were delivered to the system integrators in Gansu, for installation in early 1997. The 53-Wp PV systems were installed in elementary schools in Gansu as part of an education program associated with the project.

A major barrier to the widespread deployment of photovoltaics in China has been the variable quality of modules and balance-of-system components. Quality control is being implemented through component testing and system monitoring during the Gansu project. NREL provided modules measured under standard test conditions as secondary testing standards to the three system integrators in Gansu. Chinese-made charge controllers have been bench tested for safety and reliability at both GSELF and NREL. As a result of charge-controller testing, recommendations were made for modifications to improve safety and reliability. A testing protocol was established for testing of Chinese charge controllers used in the project prior to installation.

An extensive training program is included in the Gansu project to train users and installers and teach marketing techniques. A 2-week PV technician training seminar has been conducted in Lanzhou with 35 people attending. Most attendees were village technicians and rural energy officers. The seminar teaches basic principles of solar electricity as well as PV design, installation, and maintenance. As an outcome of the Gansu project, MOA is planning to establish a regional testing and training center in Lanzhou.

The current project emphasis is on capacity and infrastructure building to develop a commercial market for solar home systems. Partners include the rural energy office network to reduce the high cost of marketing, distribution, and service for solar home systems in remote areas. The rural energy offices at county, district, and township levels provide local market assistance to identify customers and help monitor the post-installation performance of systems. Experience gained in working with MOA and its extensive rural energy office network will help in the future expansion of the project to other parts of China. MOA has rural energy offices in 1800 of the 2300 counties in China.

Based on the results to date in the Gansu project, the Chinese MOA now plans to extend the project into five additional western provinces in China. The MOA is now planning a 10,000-solar-home-system project to be completed by the year 2000 with financial assistance from the State Council Office for Poverty Alleviation and Rural Development and local provincial agencies. NREL is providing technical assistance to the MOA in the design phase of this expanded rural electrification project. In 1997/1998, two additional projects will be initiated in Xinjiang and Qinghai Provinces.

In Xinjiang and Qinghai Provinces, the promotion of solar home systems is closely linked with economic development. The agricultural bureaus in these provinces use radio and television announcements and programs to provide vital agricultural information to remote farming and herdsmen populations, including weather reports, farm commodity price information, and information on farming methods and new practices, such as the construction of greenhouses. Radio and television is also a link in the educational system for teaching the Chinese language to minority populations in remote regions. For remote populations, solar home systems have now become so valuable that they are prized as wedding dowries and gifts of esteem.

MOA plans for infrastructure development include making use of an extensive network of agricultural service stations that are supported under the rural energy office network. These service stations normally provide repair services for agricultural machinery, but many service stations have now entered the business of selling and repairing solar home systems in remote areas. Solar home systems have become the primary business for a few of these service stations, which is conducted mainly on a private enterprise basis with minimal financial support from government sources. Some solar-home-system distributors have also contracted with village distribution outlets for electronic consumer products including radios and television sets. These village outlets sell and repair consumer electronic products and are now beginning to include solar home systems in their product inventory.

HYBRID SYSTEMS FOR REMOTE HOUSEHOLDS IN INNER MONGOLIA

The Inner Mongolia Autonomous Region (IMAR) in northern and western China has a population of about 23 million people, 14 million of whom are herdsmen. The land area of the region is 1.18 million km², and 75% of the land area consists of grasslands. The average population density in the IMAR is approximately 19 people per km², but in the remote rural areas, the population density is equal to or less than 3 people per km². The annual solar insolation in IMAR ranges between 1,280 kWh/m² and 1,860 kWh/m².

The IMAR government has been aggressive in developing renewable energy resources for both grid-connected utility and off-grid applications. In an aggressive rural energy development program over the past 10 years, more than 120,000 households have been electrified with small wind generators in the range of 100 to 300 W. In addition, more than 7000 small PV systems (total of 120 kWp) had been installed in remote households at the end of 1994. An extensive infrastructure to support rural energy development in the form of a new energy service station network was also established in 56 of the 73 counties in IMAR. This infrastructure provides installation, maintenance, and sales support services for rural energy systems.

There are still more than 300,000 remote households, 1100 villages, and 198 townships that are unelectrified in remote rural regions of IMAR. By the year 2000, the New Energy Office of IMAR plans to install 25,000 remote household systems in IMAR and a total of 80,000 remote household systems using wind, PV, and wind/PV hybrid systems in the longer term. There is also a proposed plan to electrify at least 48 township centers with renewable energy central village hybrid systems, primarily wind/diesel systems with battery storage, but also including PV as an additional component of village hybrid system configurations [3]. The use of subsidies for rural systems is being phased out and commercialization based on market forces is being encouraged. The rural population of Inner Mongolia, consisting of herdsmen and farmers, has among the highest annual income levels of the rural populations in China.

At the request of the Inner Mongolia government during 1995, NREL, the Center for Energy and Environmental Policy (CEEP) at the University of Delaware, and the Chinese Academy of Sciences in Beijing initiated a case study analysis of rural electrification options in IMAR. The project was conducted in cooperation with the Planning Commission and the New Energy Office of IMAR, which are the two key agencies responsible for renewable energy planning. Other participating organizations included the University of Inner Mongolia, the Inner Mongolia Polytechnic University, and several local companies.

The first phase of the case study project consisted of levelized cost analyses of existing systems in four counties in central and northern regions of IMAR, including Si Zi Wang, Su Ni Te You, A Ba Ga, and Dong Wu Zhu Mu Qin counties. Solar and wind resource data were collected from the four counties and performance/load data were collected from 10 PV systems, 22 wind systems, and 6 PV/wind hybrid systems, which were in the 22-W to 600-W size range. Two sizes of gasoline gen-sets, common for household and ranch use, in the size range of 450 to 500 W were examined for comparison.

The results of the levelized cost-of-energy analyses are shown in Table 1. For the types of systems currently being deployed for stand-alone electrical generation in rural areas of IMAR, wind generators are the least-cost option for household electricity in the four counties. Small wind generators in the 100-, 200-, and 300-W size range are manufactured locally in IMAR for the household market. The levelized cost of energy for small PV/wind hybrid and PV systems is higher than the cost of electricity generated by wind systems, but significantly lower than the cost of electricity from gasoline gen-sets [4].

Table 1. Levelized Cost of Energy Values for Rural Electrification Options in IMAR for Remote Households

System	Output Range kWh/year	Levelized COE \$/kWh
Wind	200-640	0.24-0.36
PV/Wind	400-900	0.30-0.45
PV	45-230	0.70-0.85
Gas Gen-Set	480-730	1.10-1.20

The use of small wind/PV hybrid systems for remote-household electricity is attractive because of the seasonal complementarity of solar and wind resources. Wind energy is relatively more available during spring and winter months than in fall and summer months. Solar-insolation levels, however, peak during summer months and are at a minimum during peak winter months. Therefore, designing wind/PV/battery-storage hybrid rural household systems that are optimized based on the local wind/solar resource mix produces an annual electric power supply for a given household-load demand that is more reliable and economical than wind or PV systems alone.

The New Energy Office of IMAR and the Inner Mongolia Planning Commission are developing plans for expanding the use of wind/PV hybrid systems by remote herdsman families for household electrification. NREL and the CEEP at the University of Delaware are providing technical assistance to these agencies in optimizing the design of such systems. Based on annual income levels, two types of systems are receiving attention. Hybrid systems in the 400 to 500 W range are being developed to serve household loads that include lighting, a color television set and radio, a small washing machine, and a small freezer, requiring approximately 1.6 kWh per day of energy. Smaller systems in the 150 to 200 W range are being developed for intermediate-income-level households that provide approximately 0.6-0.7 kWh per day for household loads that do not include a freezer or washing machine. A pilot project based on remote-household hybrid systems is in development for 300 households to be conducted in 1998. The results of this pilot program will be fed into the planning process for the larger 25,000- and 80,000-remote-household projects by the IMAR government.

RENEWABLE ENERGY VILLAGE POWER SYSTEMS

The development of village power systems in China based on renewable energy technologies is at an early stage. Village power systems in the range of 5 to 30 kW based on PV, wind, and wind/PV hybrid technologies incorporating battery storage have been installed in Tibet, Inner Mongolia, Qinghai, and on islands of some of the coastal provinces. Autonomous wind/diesel/battery systems up to 80 kW in size have also been installed in IMAR. The largest renewable energy hybrid system is installed in Shandong Province. At the end of 1994, four village systems had been installed in Tibet, with plans for three additional systems [5], and more than 12 village systems had been installed in IMAR by the end of 1996 [6].

The renewable energy hybrid village power option is viable for supplying power to unelectrified villages and clusters of households in remote rural regions of China. Such systems can also supply additional electrical generating capacity for island mini-grid applications and provide supplemental power to the local grid. Renewable hybrid systems can replace diesel and gasoline gen-sets where delivered fuel prices and O&M costs are high and can be used with diesel back-up generators to extend diesel engine lifetimes and reduce O&M costs where delivered fuel costs are lower. Nine of the IMAR systems, eight of which are wind/diesel/battery systems and one of which is a PV/battery system, have been installed by the Hua De New Technology Company, which is a German joint venture company in Hohhot [6]. The establishment of joint-venture operations has proven to be an effective way to promote technology transfer and market development in China.

Under the Energy Efficiency and Renewable Energy Protocol agreement, joint cooperation has been established between NREL and China for technical assistance related to village power development in China. The initial phase of this cooperation is in the form of personnel exchanges for training in the use of hybrid village power software applications at NREL. Training is being conducted by the Village Power Group, located in NREL's National Wind Technology Center, in the use of Hybrid2 and HOMER advanced village power design and optimization simulation models developed at NREL. The training program will be linked to project development in China. To date, personnel from the Hydropower Planning Research Institute of the Ministry of Electric Power (which has aggressive wind and wind hybrid system programs) and the Institute of Electrical Engineering of the Chinese Academy of Sciences have been trained in the use of these hybrid codes.

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